MINING AND MILLING METHODS, INLAND LIME AND STONE CO., PORT INLAND, MICH.

BY L. G. MARSHALL

* * * * * * * * * * **Information Circular 7917**

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1959

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The Library of Congress has cataloged this publication as follows:

Marshall, Lawrence G
Mining and milling methods, Inland Lime and Stone Co., Port Inland, Mich. Washington, U.S. Govt. Print. Off., 1959.

22 p. illus., tables. 26 cm. (U.S. Bureau of Mines. Information circular 7917)

1. Limestone—Michigan. 2. Inland Lime and Stone Company, Port Inland, Mich. I. Title. (Series)

[TN295.U4 no. 7917] Int 59-127

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CONTENTS

	Page
Introduction	1
Summary	1
Acknowledgments	2
History	2
The deposit	4
Exploration	4
Mining	4
Stripping	4
Drilling and blasting	6
Loading and haulage	9
Milling	9
Loading and shipping	22

ILLUSTRATIONS

Fig.		
1.	Location of mill and quarry, Inland Lime and Stone Company, Port Inland, Mich	3
2.	Aerial view of quarry	5
3.	Stripping operations	5
4.	Rotary drill	7
5.	Drill pattern and method of loading	8
6.	Quarry face before blast	10
7.	Quarry face after blast	10
8.	Cleanup cut after blast	11
9.	Loading stone for transportation to mill	12
10.	Quarry locomotive	13
11.	Aerial view of plant	14
12.	Mill flowsheet	15
13.	Crusher building	16
14.	Car dumper	16
15.	Cyclone classifier	17
16.	Rake classifier	17
17.	Stockpile stacker	19
18.	Stacker feeder belt and shuttle	19
19.	Mill buildings and transfer belt	20
20.	Transfer belt carrying stone	22

TABLES

1.	Annual production at 5-year intervals	2
2.	Present wage scales	21
3.	Cost distribution on basis of total cost, percent	21

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MINING AND MILLING METHODS, INLAND LIME AND STONE COMPANY, PORT INLAND, MICH.[1]

by

L. G. Marshall[2]

INTRODUCTION

This report is one of a series published by the Federal Bureau of Mines describing mining methods and performance at individual operations throughout the United States. The objective of these papers is to promote development and conservation of our mineral resources by disseminating reliable technological information on mining methods, practices, and results that may be applied to the engineering analysis and solution of mining problems.

SUMMARY

Operation of a limestone quarry producing flux for the steel industry and crushed stone for production of concrete is described in this report. The deposit being mined is a flat-lying limestone formation under a thin overburden 2 to 25 feet thick. The height of the quarry face varies from 9 to 60 feet, averaging 40 feet. Production rate ranges from 4.5 to 5 million long tons per year.

Blastholes are drilled by rotary drills with 6-1/4-inch tricone roller bits. They are spaced at 18-foot intervals, 25 and 45 feet from the quarry face, and drilled to a depth of 4 feet below the quarry floor. The number of holes per blast ranges from 100 to 400, averaging 200. Normally, ammonium nitrate is used as the explosive; conventional powder is used in wet holes. Powder consumption ranges from 0.36 to 0.50 pound per cubic yard, averaging 0.42 pound.

The stone is loaded into 50-ton side-dump cars by electric shovels with 5-cubic-yard buckets and hauled 7 miles in 9-car trains by electric trolley locomotive. The average cycle per trainload is 110 minutes, of which 50 minutes is required for loading and 20 minutes for unloading.

The stone is crushed and sized by grizzly, screens, and hydraulic classifiers to produce open hearth flux, two sizes of blast furnace flux, three sizes of aggregate, papermill stone, and sand.

1/ Work on manuscript completed November 1958.

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Costs are distributed as follows: Quarry operation, 33.4 percent; mill operation, 12.9 percent; maintenance, 23.4 percent; and overhead, 30.3 percent.

ACKNOWLEDGMENTS

Sincere appreciation is extended to Mr. A. W. Heitman, president, Inland Lime and Stone Company, for permission to publish this report.

Grateful acknowledgment is extended to John W. Moffat, vice president, Charles Atwater, chief engineer, and members of the Inland staff who, in giving so generously of their time and knowledge, made this report possible. All of the photographs and information for the drawings and maps contained herein were furnished through the courtesy of the company.

The company's operating office is located at Port Inland, Mich.

HISTORY

Inland Lime and Stone Company was organized December 14, 1928, as a subsidiary of the Inland Steel Co. At that time the new company acquired the assets of the Manistique Lime and Stone Co. and exercised its options on other lands in the area. The plant is located on the north shore of Lake Michigan in Schoolcraft County at the company-constructed lake port of Port Inland (fig. 1). The quarry, which is in Mackinac County, is 7 miles north of Port Inland.

Construction began in the spring of 1929. A protecting breakwater, a harbor and dock, and a railroad spur from the Minneapolis, St. Paul, and Sault Ste. Marie Railroad, at Inland Junction to the harbor, were the first projects undertaken. The projects were completed the following year. Construction of the plant buildings and installation of equipment was begun and completed during 1930.

Stripping at the quarry site began in the spring of 1930, enabling the first blasting of the limestone formation in late September of that year. The first train was loaded and the stone dumped into the primary crusher on October 6, 1930. On November 14, less than 2 years after ground breaking, a lake freighter cleared the harbor with the first cargo of limestone produced by the new company.

Table 1 lists the production at 5-year intervals.

TABLE 1. - Annual production at 5-year intervals

Year	Long tons shipped by vessel
1930.....	44,510
1935.....	1,517,034
1940.....	2,589,979
1945.....	3,281,416
1950.....	4,156,055
1955.....	4,274,132

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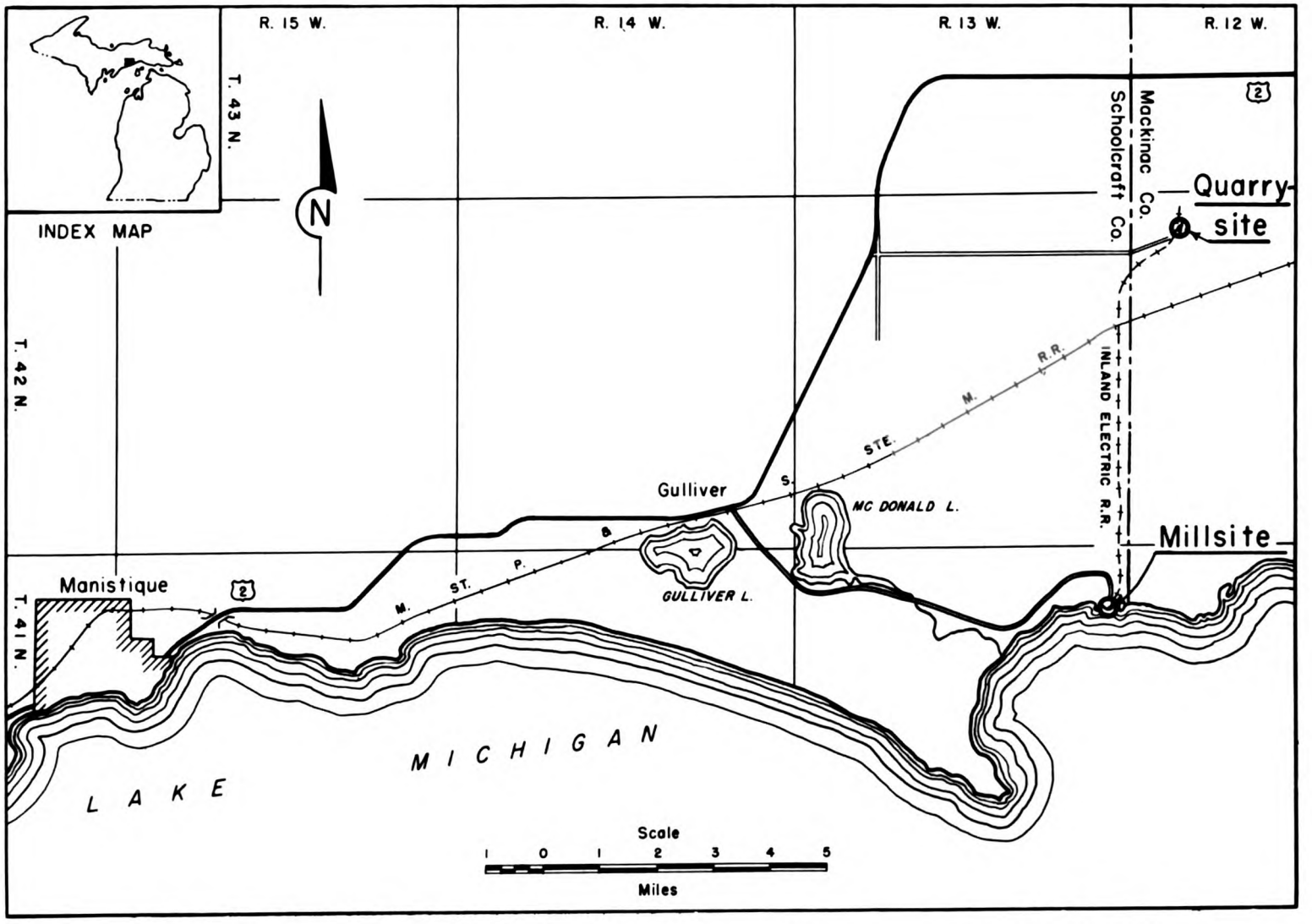

FIGURE 1. - Location of Mill and Quarry, Inland Lime and Stone Company, Port Inland, Mich.

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At present, the average total yearly production rate of material shipped by water, rail, and truck is between 4,500,000 and 5 million long tons. The plant is rated as one of the largest operations of this type in the United States.

During the early years of operation, the plant produced 6 sizes of stone. This has been increased to 14 sizes.

THE DEPOSIT

The limestone formation being exploited is the high calcium, low magnesium limestone of the Niagaran Series, Silurian System. It is of a white, buff, or brown color and is coarsely to finely crystalline with an estimated thickness of 130 feet. The deposit is comparatively flat-lying, dipping nearly 1° to the southeast. There is very little deformation although vertical seams are numerous.

In the immediate area of the quarry operations, the overlying dolomite formations have been removed by erosion, leaving a comparatively thin mantle of overburden of 2 to 25 feet in thickness. Erosion has also reduced the thickness of the limestone that has resulted in a variance in the height of the quarry face from 9 feet minimum to 60 feet maximum, averaging nearly 40 feet.

EXPLORATION

Exploration is conducted during the summer months and consists entirely of diamond drilling. Part of the drilling is done under contract and part is company-conducted.

During a drilling season the company drills from 15 to 20 EX holes. Each 40-acre land tract is explored by one centrally located drill hole. Holes vary in depth depending upon the thickness of the overburden, 40 feet of the limestone formation being penetrated at each hole. The sample interval is 5 feet and cores are analyzed for calcium, magnesium, and silica content. All holes are located by survey and collar elevations are recorded.

A factor of 2 long tons per cubic yard in place is used in making reserve estimates.

MINING

Stripping

The quarry is about 7 miles north of the plant. Stone is shipped from two adjacent operations; one, known as the West quarry (right center, fig. 2), is about 1 mile long and 600 feet wide, and the other, known as the Old quarry (center, fig. 2), is about 1-1/2 miles long by 3/4 mile wide. A second lift is being started in the Old quarry as a center cut.

Overburden ranges in depth from 2 to 25 feet. Stripping is conducted throughout the year, the greatest amount being done during the 4-month winter

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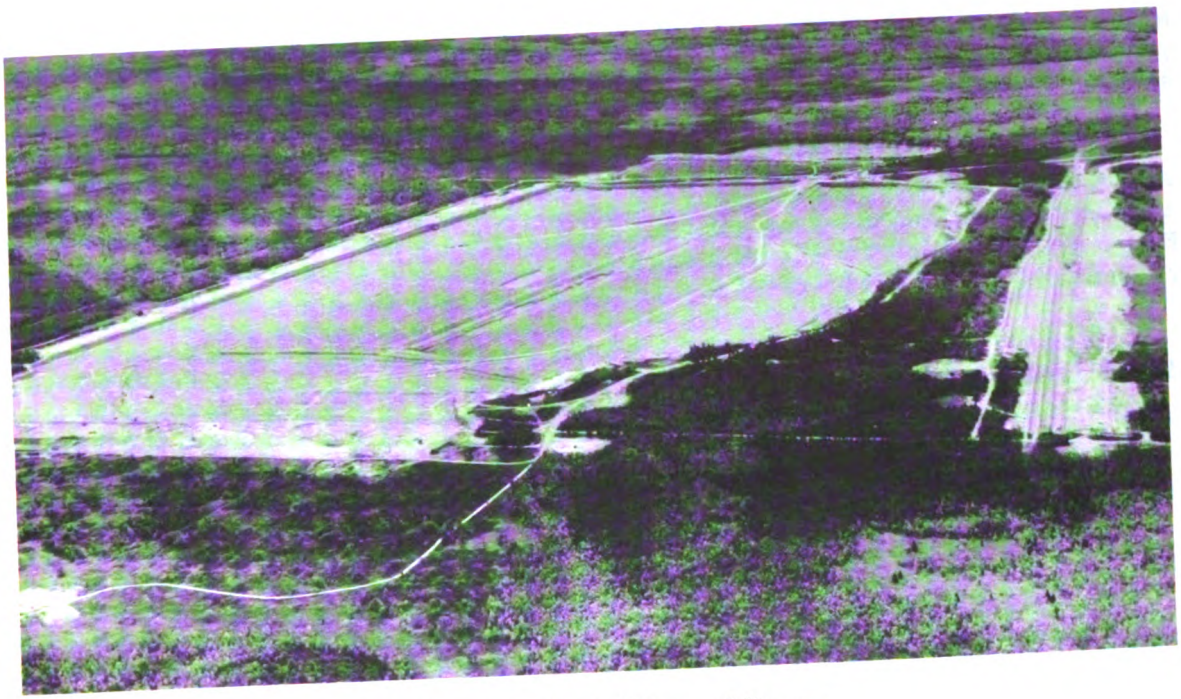

FIGURE 2. - Aerial View of Quarry.

FIGURE 3. - Stripping Operations.

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season. Between 300,000 and 400,000 cubic yards of overburden is removed yearly. Waste dumps are located on sites that are not underlain by the limestone formation.

Stripping equipment consists of two shovel-truck units. One unit consists of a 170 B Bucyrus-Erie electric shovel equipped with a 6-yard bucket and 22-ton Euclid end-dump trucks. The other unit is composed of a 54 B Bucyrus-Erie electric shovel, equipped with a 2-3/4-cubic-yard bucket, and 22-ton end-dump Euclid trucks. The maximum haul is about 2,500 feet.

During the summer months the overburden, less than 3 feet deep, is bulldozed into windrows to be loaded by the 54 B Bucyrus-Erie shovel (fig. 3). Six 22-ton Euclid trucks are used for haulage. In areas where the stripping shovels have completed their work, the final cleaning of the limestone surface is done with a fleet of dozers, consisting of one D9, one D8, and two TD14's.

Drilling and Blasting

One of the many functions of the Engineering Department is to lay out the drill holes for each blast and to keep a complete record of each hole. Usually two rows of holes are established by survey, both being parallel to an established baseline. The two rows are 25 and 45 feet from the face of the cut, with holes in each spaced at a standard interval of 18 feet. The collar elevation of each hole determines the depth of drilling, the average depth being 40 feet. All holes bottom 4 feet below the established elevation of the quarry floor. The number of holes in a single blast varies from 100 to 400 and averages 200.

Drilling is continuous throughout the year. Two electric-powered Joy Champion Heavyweight (Class 58BH) rotary drills (fig. 4), using 6-1/4-inch tricone, roller-type bits, average 180 feet per drill shift. Controllable hydraulic pressure keeps the bit against the bottom of the hole with the correct pressure for the most efficient cutting under existing conditions. Cuttings are removed from the hole by an airblast. Air, under pressure, is supplied through the drill string by an air-cooled two-stage compressor. The volume and pressure of air are enough to force the cuttings away from the bit face and up around the outside of the drill pipe to the collar of the hole. The cuttings are picked up by a centrifugal type dust collector and discharged into a hopper box for sampling. Each drill unit is mounted on 16-inch wide, independently controlled crawler treads. Moving speeds range from 29 to 117 feet per minute.

After completion of each hole a short length of 6-inch casing is inserted at the collar to facilitate loading and prevent caving. Holes are loaded in three decks (fig. 5), although in some instances it is necessary to deviate from this standard practice.

Dry, prilled ammonium nitrate is poured into the hole. It has been found, by experience, that each foot of hole will accommodate about 11-1/2 pounds of nitrate. After the proper amount has been charged, fuel oil is added by pouring it on top of the deck. About 6 quarts of oil is added per 50 pounds of

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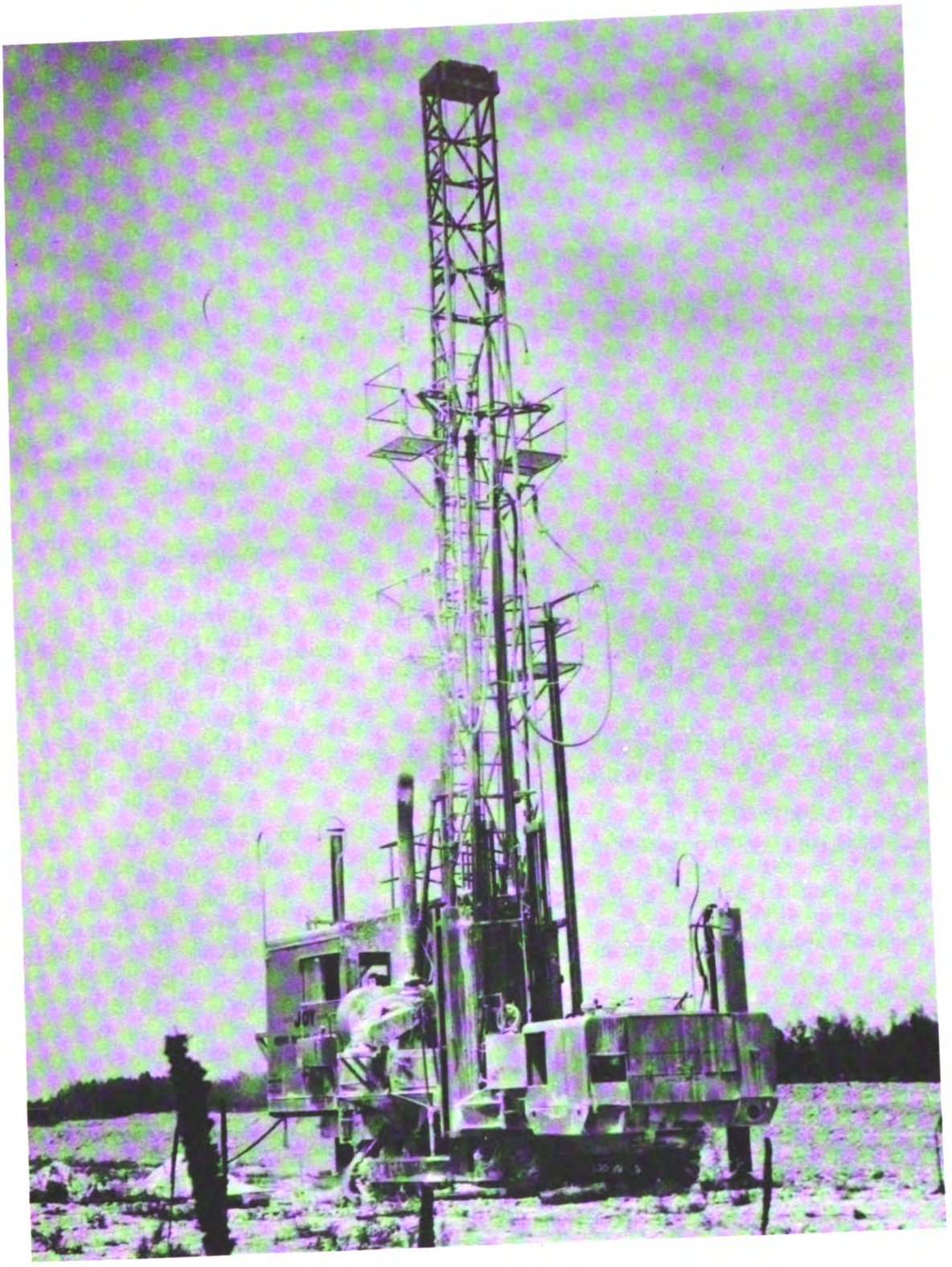

FIGURE 4. - Rotary Drill.

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nitrate. As each deck of explosives is completed, the distance from the collar to the top of the deck is recorded and the required amount of stemming added.

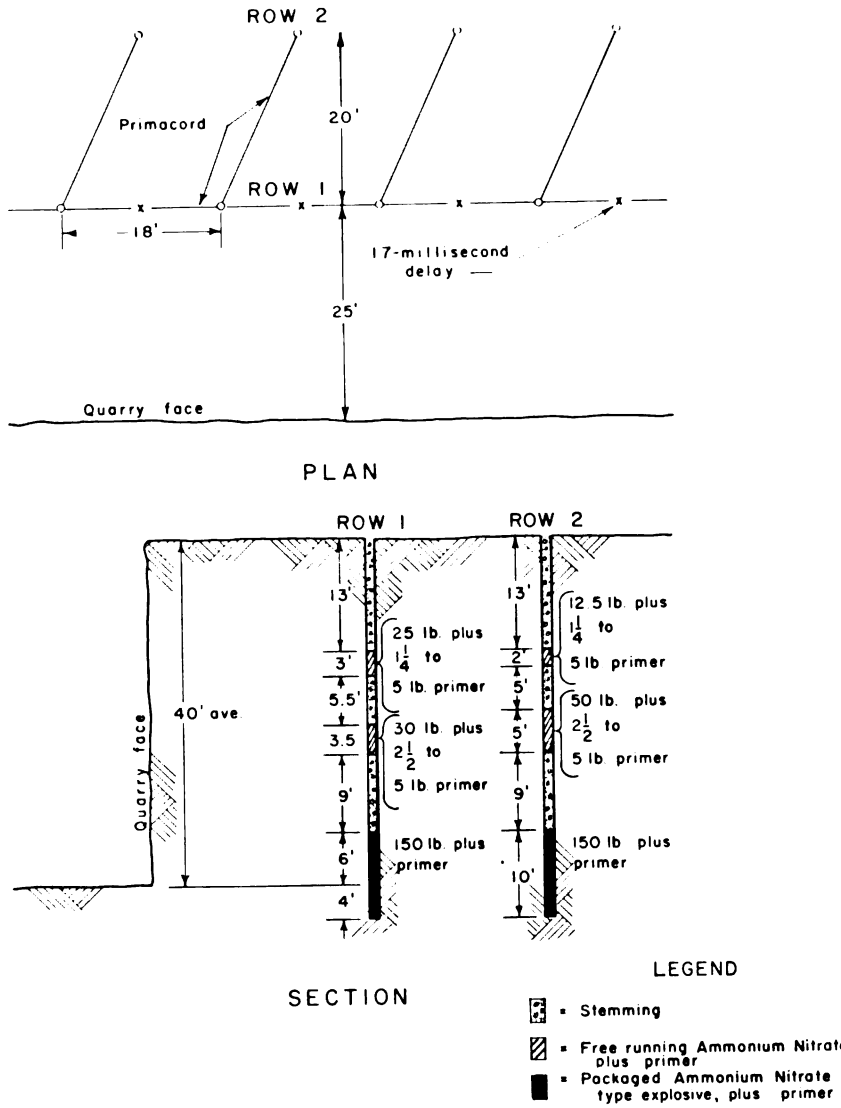

FIGURE 5. - Drill Pattern and Method of Loading.

The bottom 10 feet of both rows of holes is loaded with about 150 pounds of packaged ammonium nitrate-type of explosive, on top of which is placed a primer. In the front row of holes, the next deck consists of 9 feet of stemming composed of drill cuttings. This is followed by 30 pounds of prilled ammonium nitrate and either a 2-1/2 or 5-pound primer, occupying about 3-1/2 feet of hole. Five and one-half feet of stemming is then added. The top deck consists of 3 feet of explosives consisting of 25 pounds of ammonium nitrate, and either 1-1/4 or 5 pounds of primer. The top 13 feet of the hole is then stemmed.

Holes in the second or back row are loaded in a similar manner, the bottom 10 feet being loaded as in the first row. This first or bottom deck is followed by 9 feet of stemming, 5 feet charged with 50 pounds of ammonium nitrate and either a 2-1/2 or a 5-pound primer, 5 feet of stemming, 2 feet with 12-1/2 pounds of nitrate and a 1-1/4 or 5-pound primer. As in the first row, the top 13 feet is stemmed.

First row holes are connected by a trunkline of Primacord with a 17-millisecond delay between each hole and are paired with adjacent second row holes with Primacord (fig. 5). The Primacord is detonated with a blasting cap and safety fuse.

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The powder factor varies between 0.362 and 0.500 pound per cubic yard, averaging 0.420 pound. Depending upon the number of holes shot, between 250,000 and 400,000 tons of stone is broken per blast (figs. 6 and 7). Some block hole secondary blasting is required.

The mill produces open hearth flux having a maximum magnesium oxide content of 1.2 percent, two sizes of regular flux having a maximum magnesium oxide content of 2.0 percent, three sizes of aggregate, papermill stone sized to the customer's specification, and sand. Segregation of the different classes of stone begins in the quarry and is controlled by analysis of drill hole samples. A composite sample is taken of back row holes at 100-foot intervals. Holes at 500-foot intervals are sampled every 5 feet. The results of these analyses are entered on an assay map. From this information, the area to be blasted is zoned according to mill requirements and stone specifications. Segregation of the various types of stone as loaded enables the mill to shunt each train trip of stone into its proper circuit.

Loading and Haulage

Quarry loading equipment consists of four electric-powered, crawler-mounted 170 B Bucyrus-Erie shovels with 5-cubic-yard capacity buckets; any size stone that this bucket will handle is sent to the mill. Transformers located in the quarry supply the shovels with 3-phase current at 2,300 volts. Shovels make two passes through the blasted stone. The first, or spill cut, is a cleanup operation along the loading track (fig. 8). When this is completed the sectional standard gage track is moved to the bank side of the cleared strip by a 50T Industrial Brownhoist diesel-electric crane. The second cut (fig. 9) removes the remaining stone, leaving the face about 75 feet from the tracks.

Each train consists of a Differential Steel Car Co., 1,000-hp., trolley-type d.-c. electric locomotive and nine 50-ton side-dump cars. The power is picked up from the trolley line by a contact shoe at the top side of the cab (fig. 10). The cab and power plant utilize only a small part of the locomotive chassis, the remaining space being occupied by a 40-ton side-dump box. This is loaded in the same manner as the regular cars and increases locomotive traction on the load haul.

An average cycle for each train is 50 minutes loading, 20 minutes for the 7-mile haul to the mill, 20 minutes for dumping, and 20 minutes for the return run to the quarry.

Several passing tracks are provided along the 7 miles of track. A dispatcher communicating with all locomotive engineers by means of 2-way radio greatly increases the efficiency and safety of the haulage operation.

MILLING

The mill (fig. 11) is located at Port Inland, Mich.

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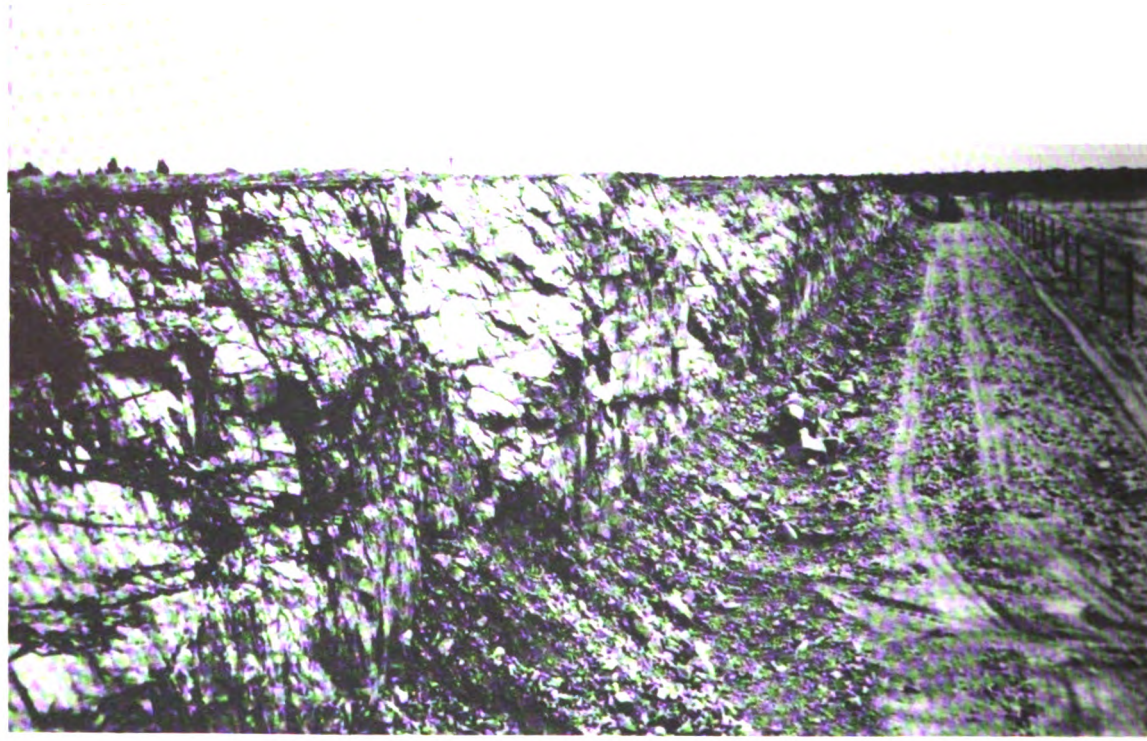

FIGURE 6. - Quarry Face Before Blast.

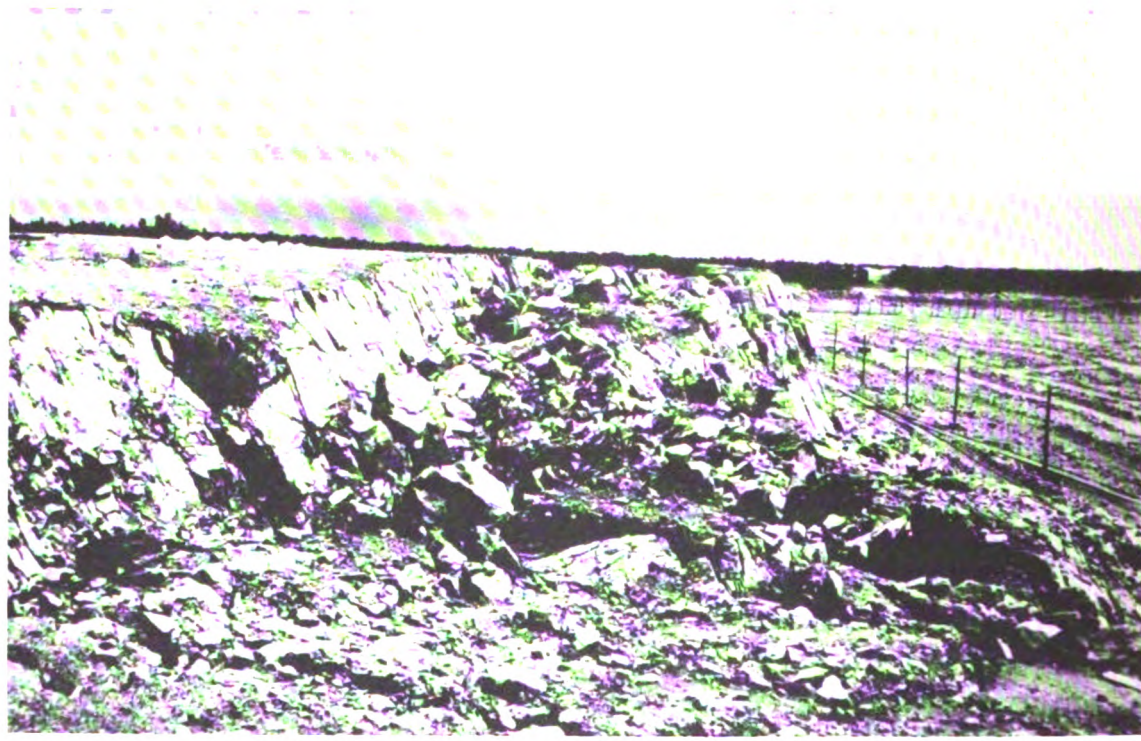

FIGURE 7. - Quarry Face After Blast.

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FIGURE 8. - Cleanup Cut After Blast.

Loaded cars from the quarry are dumped directly into the primary crusher (fig. 12), the entire train passing through the crusher building (fig. 13). Cars are dumped by means of a pneumatically operated car dumper (fig. 14) onto a 6-inch inclined bar grizzly, the oversize discharging directly into the 60-inch Superior-McCully gyratory crusher. It takes approximately 2 minutes to handle each carload of stone, or 20 minutes per train. The crusher is operated by a 250-hp. motor that moves the 60-ton breaker head in an eccentric circle of 1-3/4 inches. Primary crushing is intended to reduce the maximum size mill feed to 12 inches. The crushed stone is transferred by an Amsco pan feeder to a 48-inch belt conveyor, which carries the stone through an underground tunnel from the bottom of the crusher building, up an incline into the top of the grizzly house.

In the grizzly house, live-roll grizzlies are used for the primary sizing operation. The live-roll grizzly consists of a series of grooved rolls, all revolving in the same direction and mounted laterally in a sloping plane within a steel framework. Grooves in adjacent rolls match to form circular openings gaged to pass the desired size stone. Revolving action of the rolls induces maximum tumbling of the stone increasing sizing efficiency.

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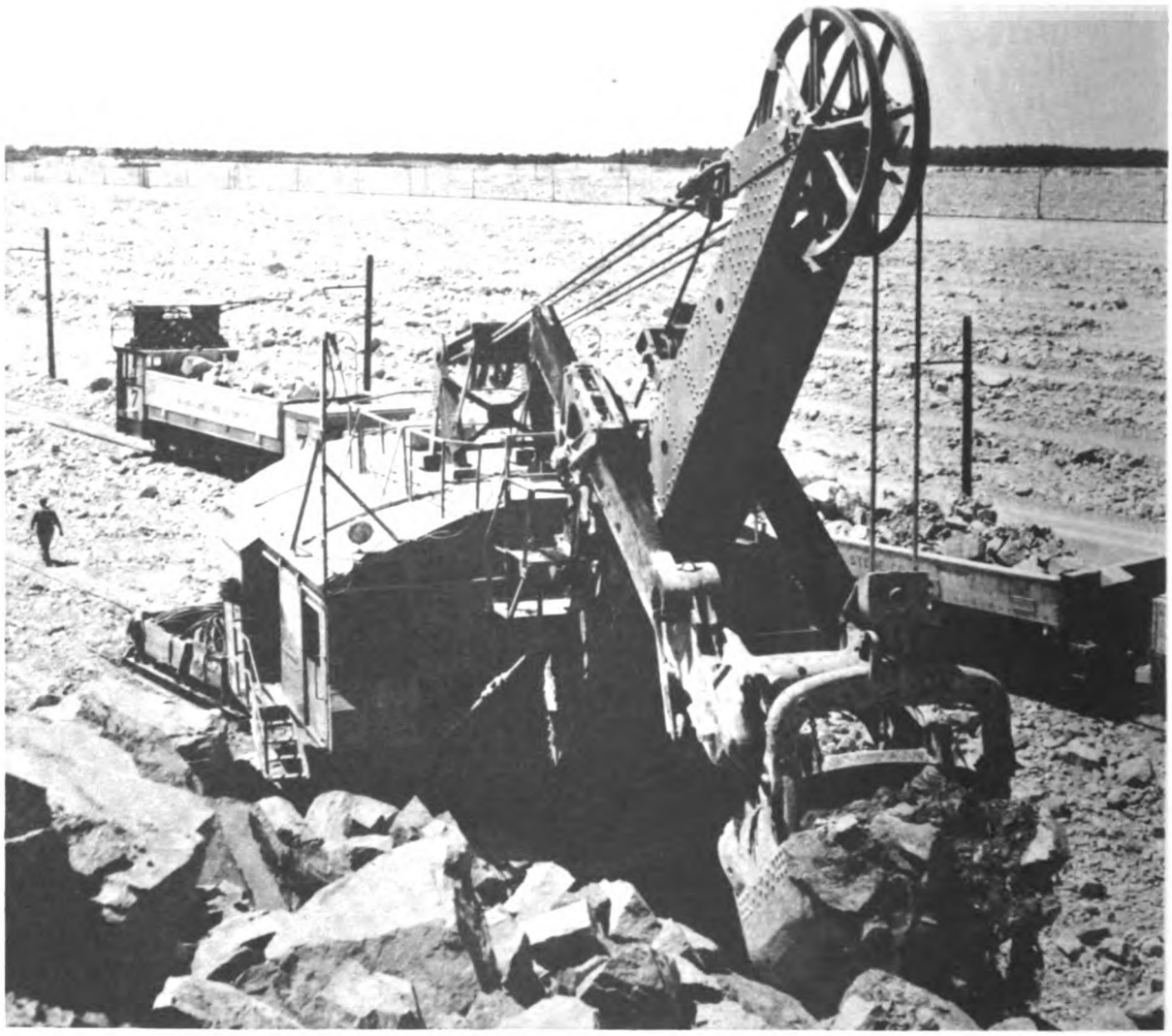

FIGURE 9. - Loading Stone for Transportation to Mill.

The stone first passes over a 12-inch live-roll grizzly; the oversize, known as papermill stone, is either chuted into a railroad car or is conveyed to a No. 20 McCully crusher in the secondary crusher house for further reduction and shunted into the screen house circuit. Undersize passes directly onto two 6-inch roll grizzlies.

Oversize from the 6-inch rolls is fed onto a belt conveyor that carries it directly to a stacker for stockpiling as open hearthstone. Otherwise, this product is diverted to a 42-inch belt conveyor that discharges into a No. 20 McCully crusher in the secondary crusher house. Here the material is crushed to minus-6-inch. The crusher discharge passes over a 6-inch live-roll grizzly, through a slugger roll, onto a 48-inch conveyor that carries the stone to the

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FIGURE 10. - Quarry Locomotive.

top of the screen house and onto the double-deck vibrators. Undersize from the 6-inch roll grizzlies, in the grizzly house, is carried by a system of belt conveyors to the top of the screen house. Here, three sets of multideck vibrating screens are used for sizing the stone.

The first unit is a double-deck screen with a rating of 3-1/2 to 4 inches and 1-1/2 to 2-1/4 inches. Oversize of the top screen is carried by a belt conveyor to the No. 2 stacker and stocked as 4- to 6-inch flux. Oversize from the bottom deck is conveyed to the No. 3 stacker as small or 1-3/4- to 4-inch flux. Undersize material is discharged onto a triple-deck vibrator screen rated as 3/4 to 1-1/8 inches, 1/4- to 1/2-inch, and 1/8- to 3/16-inch. These screen sizes can be changed to meet customer's specification. Oversize from the top deck is conveyed to No. 4 stacker as aggregate, or it can be recirculated, with the oversize from each deck of the first unit to the secondary

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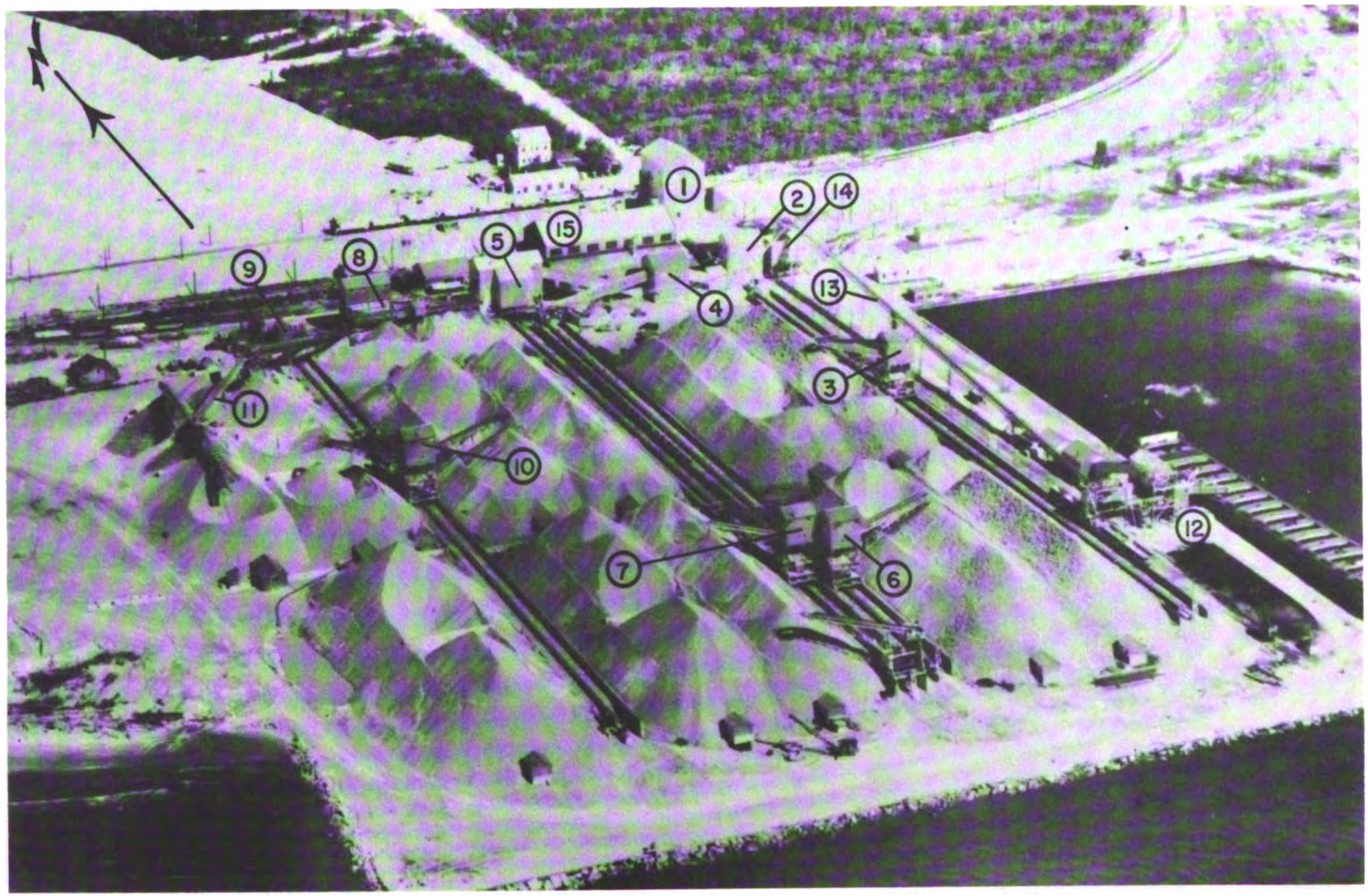

FIGURE 11. - Aerial View of Plant: (1) Primary crusher house; (2) grizzly house; (3) stacker No. 1 (open hearth flux); (4) secondary crusher house; (5) screen house; (6) stacker No. 2 (large flux); (7) stacker No. 3 (small flux); (8) temporary storage bins; (9) transfer house; (10) stacker No. 4 (large aggregate); (11) elevated shuttle (small aggregate and sand); (12) vessel loading shuttle; (13) waste belt conveyor; (14) waste bins; (15) warehouse, repair shop, and electric shop.

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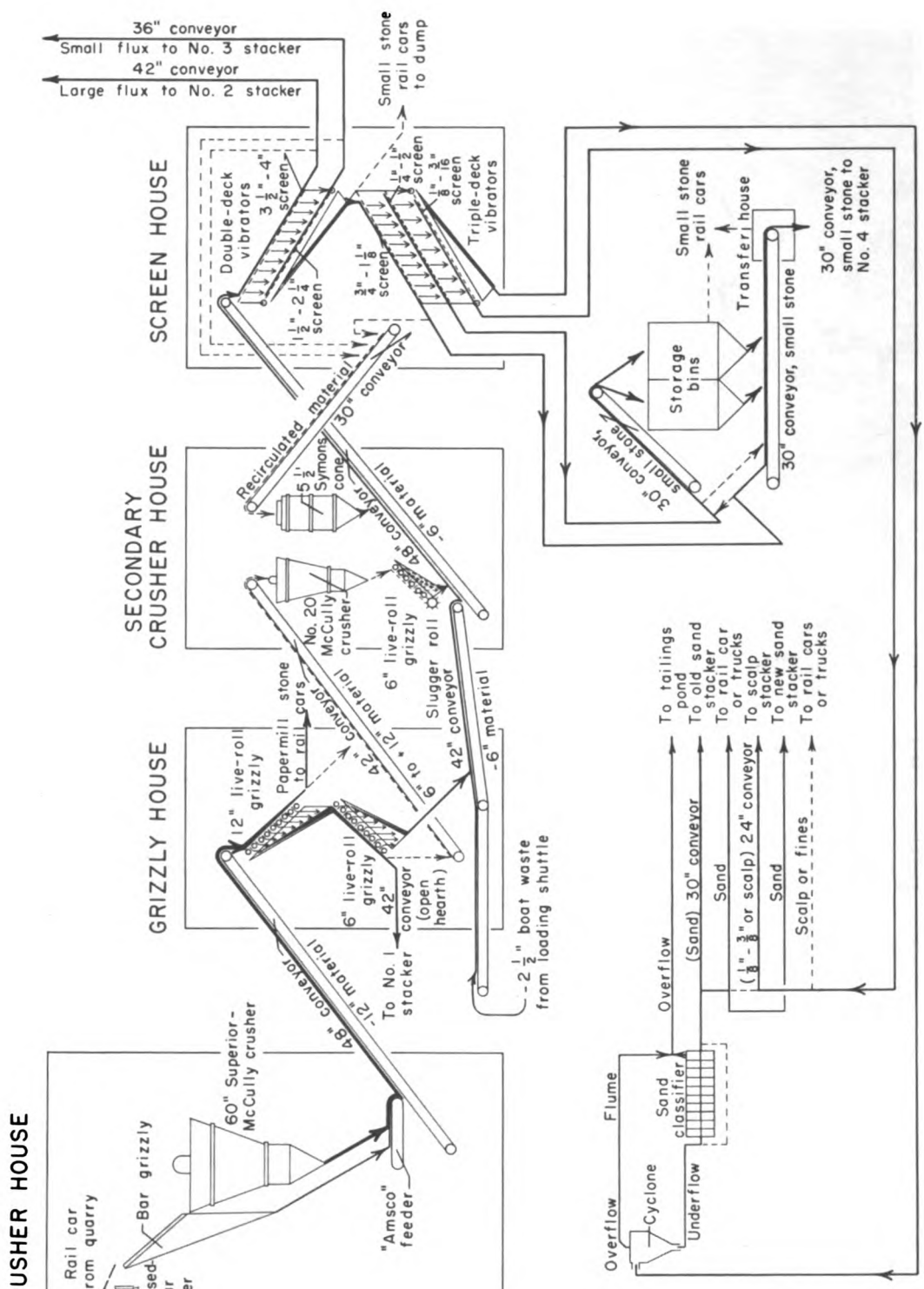

FIGURE 12. - Mill Flowsheet.

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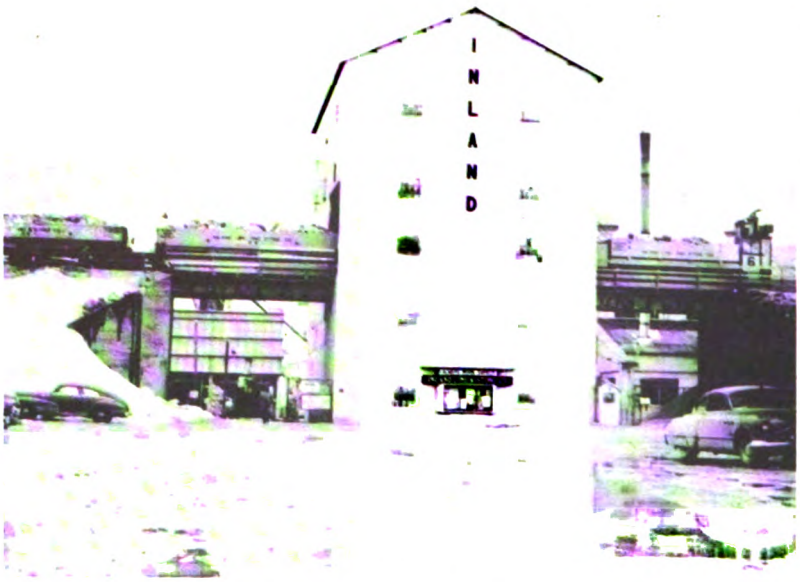

FIGURE 13. - Crusher Building.

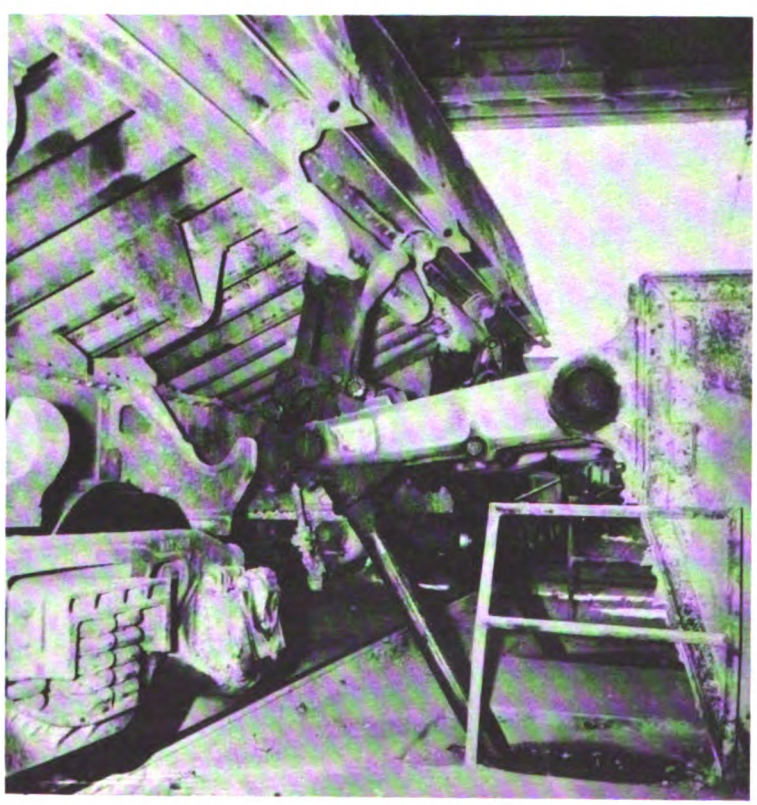

FIGURE 14. - Car Dumper.

crusher house for further reduction in a 5-1/2-foot Symons cone crusher. Oversize from the second deck is either stored in bins, for rail or truck haulage, or is sent to the No. 4 stacker. Oversize from the third deck is stockpiled as 1/8- to 3/8-inch aggregate.

The size of stone produced can be varied by changing the screen panels in the lower vibrators. Large and small flux are always separated by the upper vibrators; stone passing the bottom screen of the upper vibrators can be separated by the lower screens into a dozen of the smaller commercial sizes of aggregates and sand.

Water is constantly sprayed over the stone as it passes over the screens. This washing requires about 4,000 gallons of water per minute.

Material that passes through the bottom screen of the lower vibrator is classed as stone sand. It flows in suspension with the wash water out of the screen house into a tank, then pumped to a cyclone classifier (fig. 15). This unit is designed to separate finely divided solids suspended in water. Sand and water entering the cone-shaped unit on a tangent under pressure produce a whirling action, throwing the coarse material outward in the cone, forcing it to the bottom of the unit where, partly dewatered, it is discharged. Finer material is forced upwards through the center of the unit and out the

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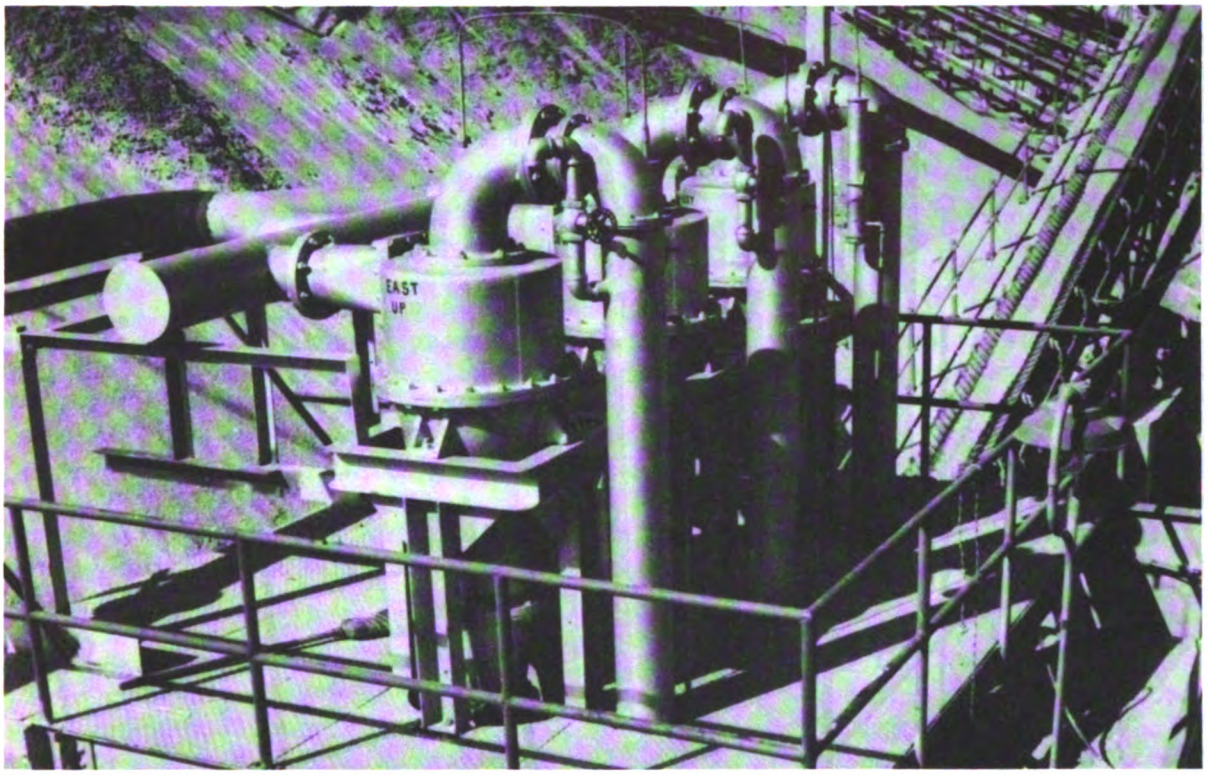

FIGURE 15. - Cyclone Classifier.

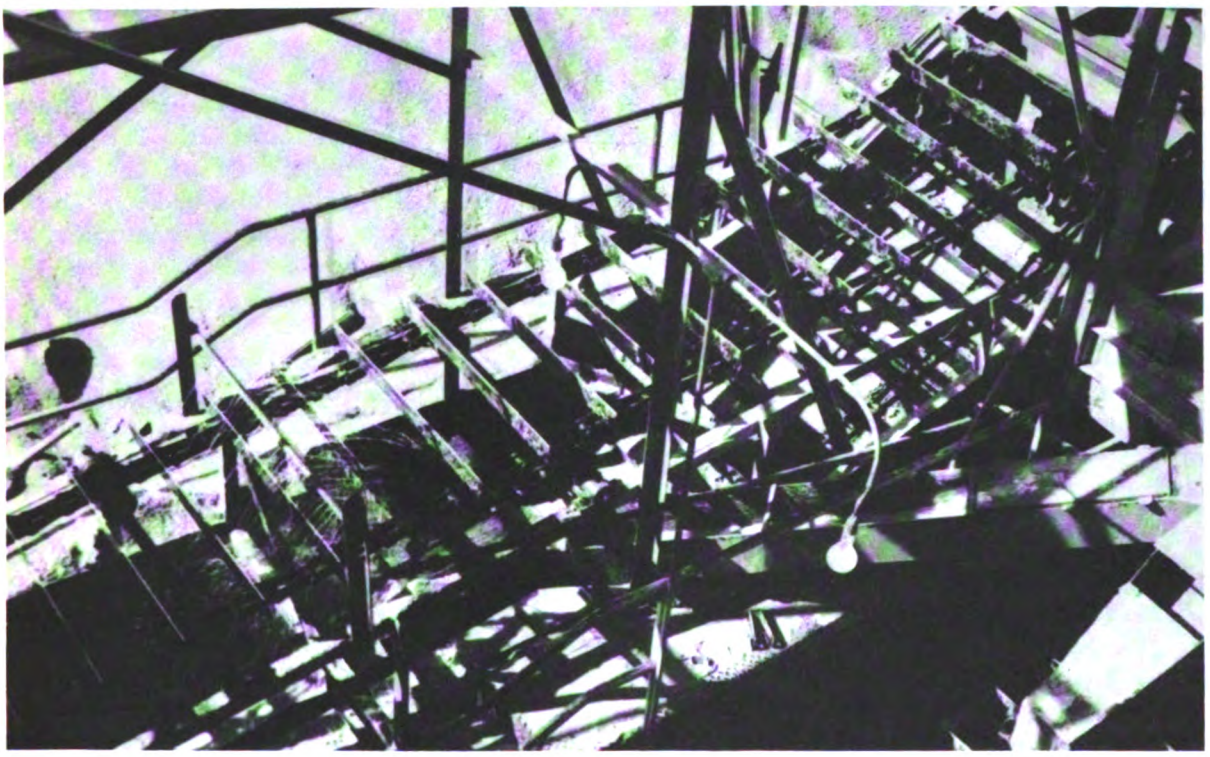

FIGURE 16. - Rake Classifier.

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top, where it flows through a flume into the tailings or settling pond. The underflow is further treated by two rake classifiers (fig. 16), the product being stored as sand.

The link that binds all the mill operations together is the belt conveyor system. Belts used are constructed to withstand the abrasive action of the stone and the impact of the larger size pieces. Belts used range from 24 to 60 inches in width. There are 57 conveyors in the plant with nearly 5 miles of belting.

After the stone has been crushed and separated into the various desired sizes, it is ready for the final steps of stockpiling and shipment. Stockpiles are arranged in six rows, each divided into a north and a south half (fig. 10). Each pile, at full capacity, is 50 feet high and 400 feet long and contains 15,000 tons of aggregate in live storage. Metallurgical stone (open hearth, large flux, and small flux) is stored in three separate rows in the east half of the storage area. The remaining three rows are the aggregate sizes and sand, which are subdivided by bulkheads into smaller piles to separate several stone sizes.

Metallurgical and larger sizes of aggregate stone are carried from the grizzly house, screen house, or storage bin on belt conveyors to the top of 56-foot stackers (figs. 11 and 17); they are then discharged into the storage piles. These traveling stackers are structures spanning the storage belt conveyors; mounted on wheels, they operate on tracks laid on top of two concrete walls 25 feet apart and running the entire length of each stockpile. Each conveyor belt leading to the stacker is about 1,800 feet long and is operated between 300 and 450 feet per minute.

Stone entering the stacker on the feeder belt is discharged onto a boom belt running at right angles to and extending over the stockpile. The stacker feeder belt (fig. 18) then passes over a tandem drive, which is at the bottom of the stacker, and on out to the tail pulley at the end of the pile. The tail pulley maintains a constant tension on the belt by means of a series of takeup weights. As stone is built up to the crest of the stockpile, the stacker is moved along slowly to maintain the crest height.

Traveling shuttles (figs. 11 and 17) stockpile the smaller sized aggregates including sand. Inclined belt conveyors transport the sized material from the screen house and the sand classifiers to the 75-foot high shuttles. These shuttles consist of horizontal belt conveyors mounted on a traveling carriage, allowing discharge to the stockpiles at any desired point.

Underlying the storage area is a system of conveyor tunnels designed to reclaim nearly one-half of the stored material. The system is made up of one main reclaiming tunnel, lateral to and centrally located to the long axis of the stockpiles, and a gathering tunnel under and parallel to each of the six stockpiles.

Chutes are located at 20-foot intervals in the roof of all the gathering tunnels. Chute gates are operated by winch and cable and discharge directly

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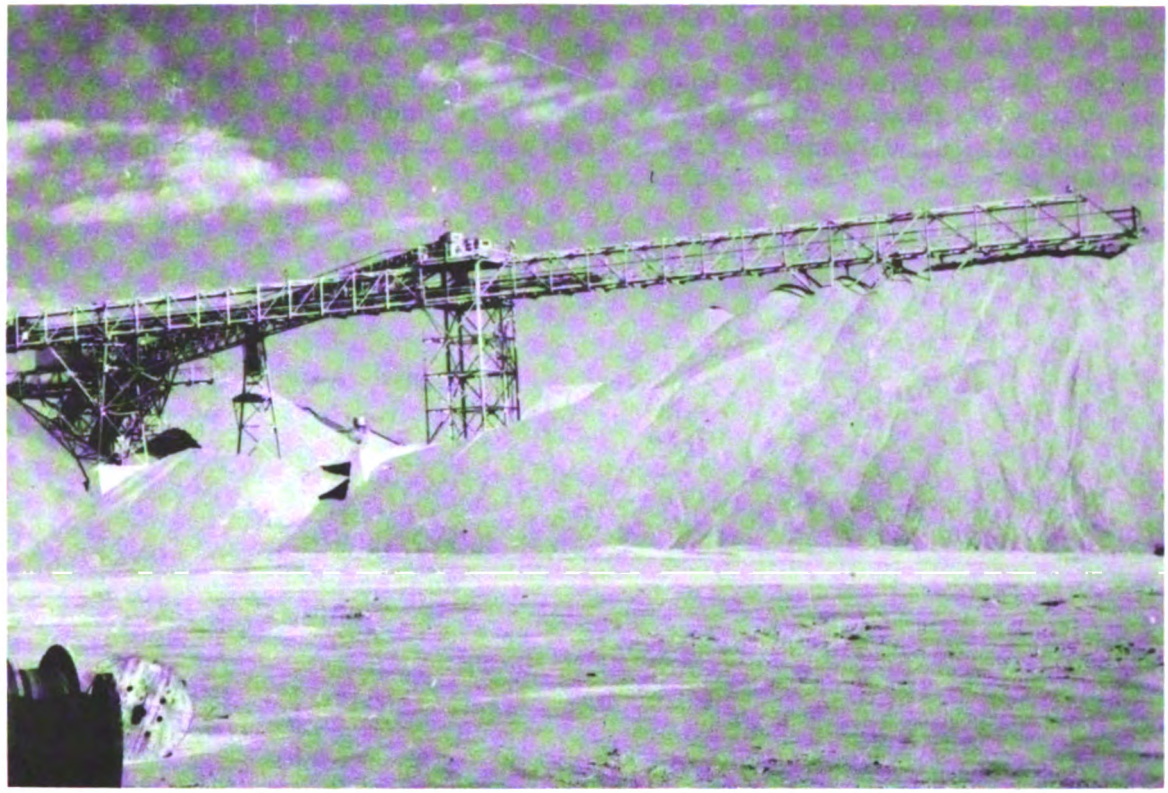

FIGURE 17. - Stockpile Stacker.

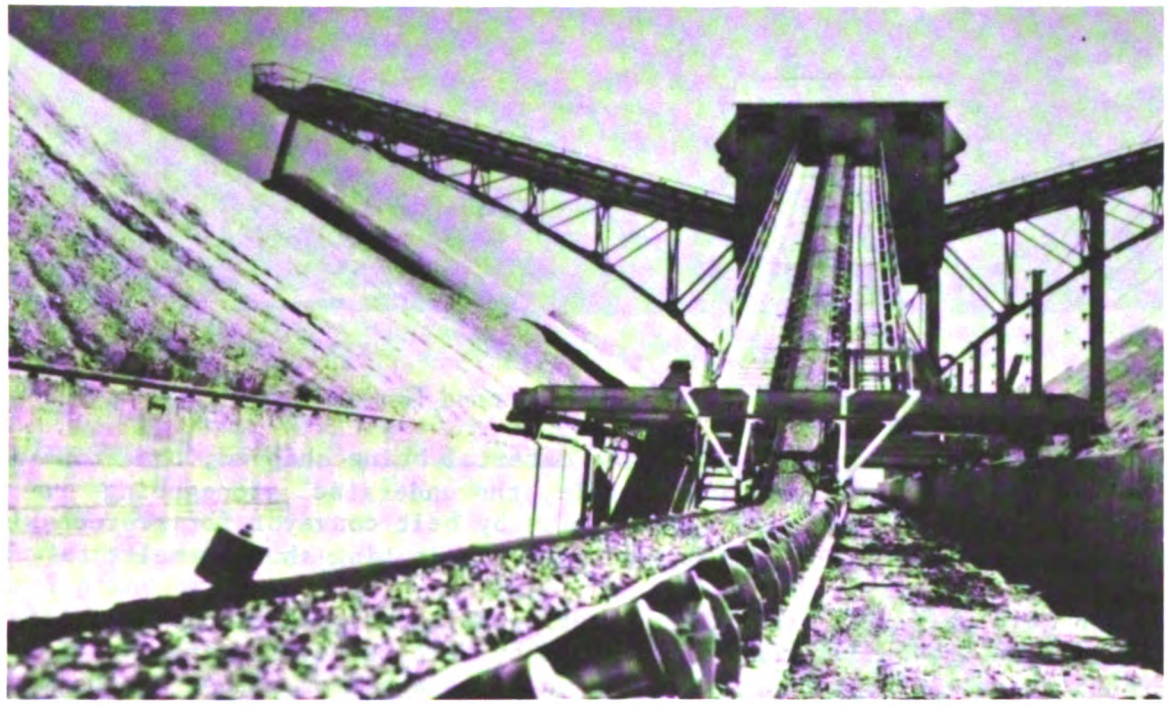

FIGURE 18. - Stacker Feeder Belt and Shuttle.

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onto the gathering belt (figs. 19 and 20). Gathering belts discharge through transfer chutes onto the main belt conveyor for delivery to the final loading shuttle. Before discharging into the loading shuttle, the reclaiming belts pass over a weightometer that automatically records the weight of material being loaded. Simultaneous drawing from more than one stockpile provides blending of various sizes of stone.

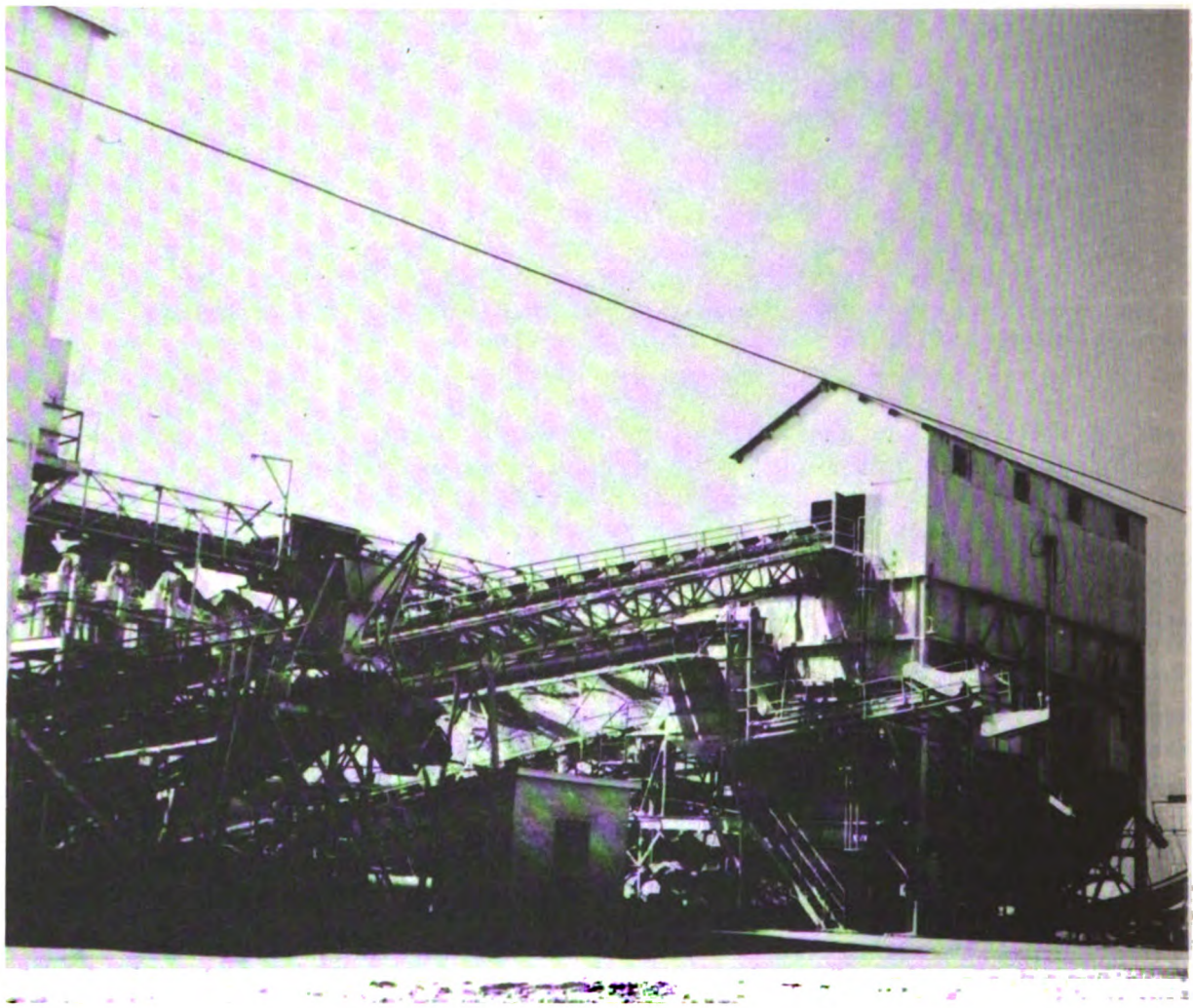

FIGURE 19. - Mill Buildings and Transfer Belt.

To insure a minimum of undersize material being shipped, the stone is finally screened in the loading shuttle, the undersize stone being returned to the 1,000-ton mill storage bins by belt conveyor for reprocessing. Specification material is discharged onto the loading shuttle belt.

In this system of stockpiling over tunnels, only about one-half of the stone in the stockpiles can be reclaimed by belt conveyors, gravity flow through the reclaiming chutes ceasing when the angle of repose of the material is reached. The remaining half is considered dead storage and becomes the base of the stockpile. In an emergency, scrapers or other suitable equipment are used for recovery.

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The prevailing wage scale is given in table 2, and the cost distribution is shown in table 3.

TABLE 2. - Present wage scales

Job class	Hourly wage,1/ July 1, 1957, to June 30, 1958	Hourly wage, July 1, 1958, to June 30, 1959	Job class	Hourly wage,1/ July 1, 1957, to June 30, 1958	Hourly wage, July 1, 1958, to June 30, 1959
1-2	1.890	1.960	12	2.310	2.480
3	1.932	2.012	13	2.352	2.532
4	1.974	2.064	14	2.394	2.584
5	2.016	2.116	15	2.436	2.636
6	2.058	2.168	16	2.478	2.688
7	2.100	2.220	17	2.520	2.740
8	2.142	2.272	18	2.562	2.792
9	2.184	2.324	19	2.604	2.844
10	2.226	2.376	20	2.646	2.896
11	2.268	2.428			

1/ The labor agreement includes a cost of living adjustment clause that adds another 12¢ per hour to the rates in column 1 as of Jan. 12, 1958.

TABLE 3. - Cost distribution on basis of total cost, percent

	Labor	Supplies	Power	Total
Quarry operation:				
Clearing and stripping	2.8	1.5	0.2	4.5
Drilling	3.1	1.2	.5	4.8
Blasting	1.0	6.3	-	7.3
Loading	3.9	.3	.6	4.8
Haulage	8.2	.7	1.7	10.6
Miscellaneous	0.7	.2	.5	1.4
Total	19.7	10.2	3.5	33.4
Quarry maintenance	6.5	5.2	.2	11.9
Mill operation:				
Crushing, milling, and stockpiling	4.8	.3	1.9	7.0
Miscellaneous	4.2	1.2	.5	5.9
Total	9.0	1.5	2.4	12.9
Mill maintenance	5.3	5.5	0.7	11.5
Other:				
Supervising, engineering, office	8.3	1.0	-	9.3
General plant expense	-	21.0	-	21.0
Total	8.3	22.0	-	30.3
Grand total	48.8	44.4	6.8	100.0

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LOADING AND SHIPPING

Port Inland harbor has a depth and size sufficient to accommodate the largest lake freighter. Its dock face, about 900 feet long, is sheathed with steel sheet piling. During the shipping season, generally from April to December, an average of 2 vessels per day are loaded. A dredge operates almost continuously in the harbor to maintain the specified harbor depth.

FIGURE 20. - Transfer Belt Carrying Stone.

When loading a vessel, the loading shuttle boom conveyor is extended outward at right angles to the dock face and lowered to discharge into the hold. Under normal conditions it takes nearly 5 hours to load an average cargo of 10,000 tons.

Railroad cars to be loaded are switched by diesel locomotive onto the loading tracks, which are on the opposite side of the shuttle from the dock face. When the car is in position the shuttle boom is extended outward at right angles to the track and discharges into the car. As each car is filled, the next car moves into position.

A railroad car can be loaded to its full capacity in a very few minutes. A train consists of six to eight railroad cars. Loaded trains are hauled via the company railroad line to Inland Junction, 5 miles away, where the cars are switched to the Minneapolis, St. Paul, and Saulte Ste. Marie Railroad. An average of about 200 cars is loaded each month throughout the year.

Nearly 10,000 tons of stone is hauled annually from the plant, and about 2,000 trucks are loaded each year. When the plant is producing the desired size stone, trucks can be loaded directly from the belt conveyor by means of chutes. To load a truck from any of the aggregate or sand stockpiles, a shovel dozer or crane must be used.

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